High-Resolution Structure Of Bioluminescence Potential In The Nearshore Coastal Waters: Processes And Prediction

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LONG-TERM GOALS

The long-term goal is to advance our understanding of the ecology of bioluminescent organisms and the mechanisms governing the temporal and spatial variability of bioluminescence in the coastal ocean. With improvements in technology, finer-scale resolution and concurrent physical, chemical and biological data over relevant scales will enable better predictability of bioluminescence events in the nearshore coastal ocean.

OBJECTIVES

One of the primary objectives is to develop and integrate a bioluminescence autonomous underwater vehicle (AUV) capability into the existing observation networks to examine dynamics in coastal waters. This new platform is able to sample and define the relevant scales of bioluminescence and advance our understanding of the processes governing its temporal and spatial variability. This, combined with the forecasting objectives of the observational networks, will also provide a mechanism and framework for predicting bioluminescence potential in the coastal ocean.

APPROACH

The approach was sequential: first, modify, design and fabricate bioluminescence bathyphotometer (BBP) for integration into a new generation of the Remote Environmental Measuring UnitS (REMUS) vehicle. Second, modify, design and fabricate AUV for measurements of nearshore coastal bioluminescence. Third, deploy the AUV in various coastal locations, some in areas of existing observational infrastructure (i.e. Monterey Bay, LEO-15). Lastly, to assess the AUV as a tool for quantifying coastal bioluminescence and explore questions uniquely addressable by using this platform. As this vehicle application is new, a significant part of this project is also to develop the platform and define its capabilities.

WORK COMPLETED

From October 2000 to June 2001, the new bioluminescence detector compatible with the REMUS AUV was designed and fabricated. The new nosecone combines the technology of the second-generation bathyphotometer with the REMUS nosecone design to minimize drag with the front section acting as a light baffle, and more importantly to obtain water in the front of the vehicle that has not

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been previously stimulated. The bathyphotometer nosecone was also made to accommodate a number of other instruments of interest; a Seapoint fluorometer, an Ocean Sensors CTD and a Seapoint optical backscatter sensor. In March 2001, a REMUS training mission San Clemente Island. Training included general operation, mission planning, and vehicle maintenance on five missions. In July 2001, the nosecone was integrated (electronically, mechanically) with the REMUS vehicle at Woods Hole. In July 2001, the REMUS vehicle with the integrated bioluminescence nosecone was delivered and an AUV team was established. Three initial successful test missions of the vehicle took place in daylight in Great Bay off of RUMFS. From these initial field tests to July 14, 2003, the vehicle has successfully completed 25 missions for a total of approximately 354 km (Table 1). These missions have taken place on both coasts and have provided valuable bioluminescence data as well as performance data on the vehicle. The vehicle was refurbished and additional batteries were installed. Eleven missions were conducted off Cal Poly's new Marine Science station in San Luis Bay. Four missions were conducted in Monterey Bay in support of the SPOKES 2002 experiment. In 2003 the vehicle was upgraded with additional Flash memory (1GB) with a new processor to allow for higher frequency data collection with the CTD and ADCP. In addition, the acoustic navigation system for the vehicle was upgraded from an analog system to digital to increase mission range.

RESULTS

Result highlights obtained in fiscal 2002-2003 are reported here and are broken down by the particular science objectives of mission or groups of missions. Some of these results are based on analysis done on data collected in 2001-2002. With each overall science objective will be a brief description of the significant results and new capabilities generated by the effort. The first two address the operational advancements of the vehicle with the remaining focused on science related questions.

Vehicle Functionality in Shallow Coastal Environments: In order to test the limits of the vehicle in shallow turbulent waters, the vehicle was deployed near the surf zone in Monterey Bay off Moss Landing. The vehicle was able to collect data in 4 meters of water along the sandy west coast of Monterey Bay in 3-meter seas. The vehicle mapped the fresher water discharge from the Elkhorn Slough and showed that the plume of estuary water hugged south of the estuary in a band about 200m wide.

Extended Mission Tests: The extended mission was implemented to collect data over longer horizontal space scales (see below). As such, the REMUS designed for shallow nearshore environments was programmed to fly over the Monterey Canyon 18km outside the range of the acoustic navigation network. Operationally, this was a new application for the vehicle and significantly extended the functional horizontal range of the vehicle.

Significant Spatial Scales of Variability: The extended missions of the vehicle allowed for a more comprehensive assessment of scales of variability as a function of distance offshore. Significant scales were quantified by variogram analysis using residuals of a General Additive Model. Bioluminescence was found to significantly vary on horizontal space scales of ~100 meter inshore (<10km) versus an order of magnitude less offshore (>10km). These results were directly related to the bioluminescent community, with the bioluminescence signals in areas dominated by zooplankton varying on shorter scales. This has significant ramifications for process studies and ecosystem assessment, where these scales (~10m) for sampling are not readily attainable.

Ecotone Identification: Data from this project have been used in a new approach to examine multidimensional relationships between bioluminescence and other physical and biological variables.

Hierarchical clustering techniques were used to define unique water masses or water types based on temperature, salinity, density, fluorescence and optical backscatter. Subsequent water masses were then examined using Generalized Least Squares ANOVA to determine if the bioluminescence in those water types was different. Results were highly significant ($p<<0.001$) and demonstrated that clustering techniques were successful in defining unique water masses. Repetitive temporal sampling of particular areas (i.e. Monterey Bay) allows for ecotone classification (with specific bioluminescence signatures) for testable prediction.

Modeling Efforts for Particle Trajectories: Repetitive time series of spatial data from Monterey Bay is also being used to further validate an early Lagrangian model run (Shulman 2003), testing the ability to predict bioluminescence as passive particles. Data from the REMUS provides true time series testing of particle trajectories as outputted from the ICON model. Data has been sent to NRL Stennis (I. Shulman) for assimilation.

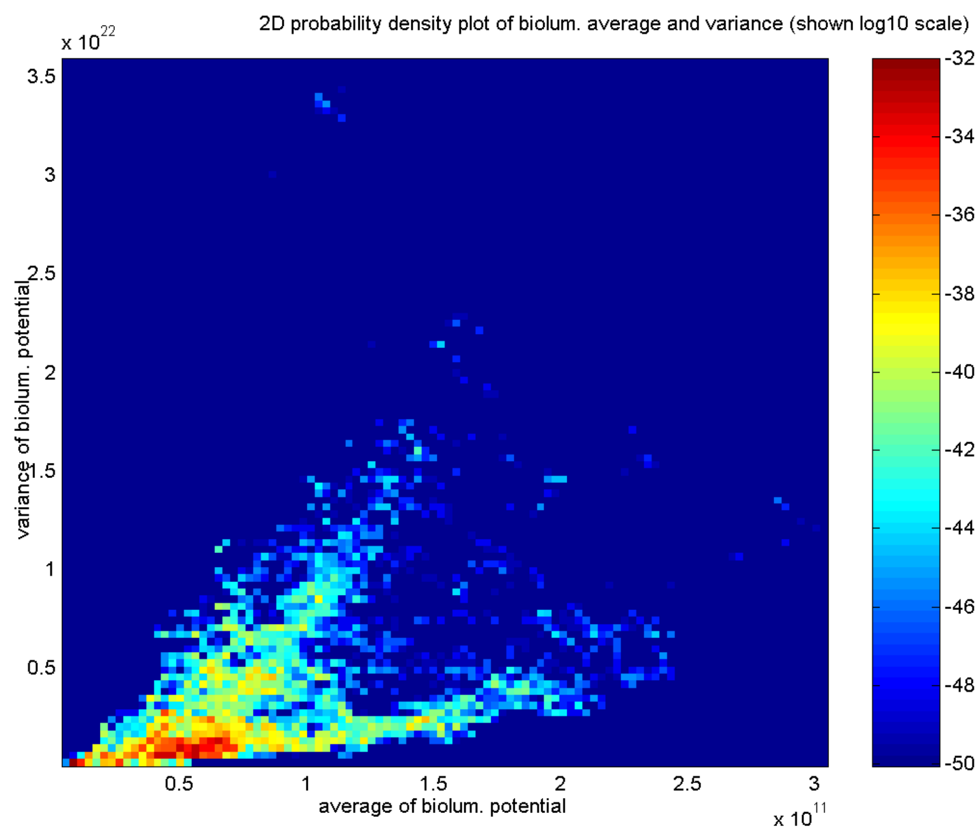

Figure 1. Density plot of the ratio of bioluminescence potential and the signal variance. This approach effectively separates phytoplankton from zooplankton with the higher slope being phytoplankton.

Bioluminescence as a Tool for Discriminating Trophic Structure: As bioluminescent organisms differ with respect to bioluminescent flash intensity and duration, signals measured by the bioluminescence bathyphotometer were used to discriminated between zooplankton (higher flash signal) and phytoplankton (lower background signal). A number of methods were attempted to look at separating the signal, such a skewness and route mean square. By examining the variance in bioluminescence as a function of the intensity of the signal, the dataset bifurcates in two general relationships (Figure 1). This is a new way to effectively separate out phytoplankton from zooplankton and has significance as an effective tool for rapid assessment of distribution as well as validation of ecosystem modeling output. Further work will be done to test the robustness of this relationship as a function of time and place.

Determination of Temporal Scales of Significant Change: Twenty-eight successive passes along the same 1.5km transect line in San Luis Obispo Bay were conducted to statistically determine the temporal variability in coastal bioluminescence. A generalized additive model was used to predict bioluminescence and run successively using every pass to predict each successive pass. At approximately 4 hours, the error associated with the prediction of bioluminescence leveled off suggesting that 4 hours was the time interval for significant change in the spatial distribution of bioluminescence. Similarly in efforts on the East Coast, the vehicle was deployed to examine the temporal effects of tides on a frontal zone. We observed a decrease in the coefficient of variation suggesting a dissipation of the front with the slack tide.

IMPACT/APPLICATION

The new bioluminescence AUV is functional and robust in the coastal environment. This project has demonstrated sustained use of this platform has increased the vehicle's sampling performance and has advance the ability to detect fine-scale vertical/horizontal gradients in bioluminescence. This project has also helped to provide relevant scales of temporal and spatial scales of change and has developed an effective approach to separating out trophic structure in the coastal environment, both vital for ecosystem model parameterization and validation.

TRANSITIONS

This project adds a new high-resolution nighttime bioluminescence capability to observation networks. Fine-scale vertical bioluminescent measurements off the coasts of New Jersey and California have improved the ability to predict bioluminescence events in the nearshore littoral regions of the marine environment. In addition to providing the basic science and ecology of bioluminescence, the AUV provides important performance data that will help to fully characterize the instrument system for the Navy.

RELATED PROJECTS

Projects that have either supported or benefited from this project through collaborations include; ONR-HyCODE program (N000149910197) with O. Schofield (Rutgers University), ONR-Biology/Chemistry (N00014-00-1-0008) with J. Case (UCSB), REMUS instrument development with C. VonAlt (WHOI), MUSE with S. Haddock (MBARI), SPAWAR Systems with R. Arrieta and B. Fletcher.

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